PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Apparatus for Heating Fluids and Tubes for Disposal Therein

We, ESSO RESEARCH AND ENGINEERING COMPANY, a Corporation duly organised and existing under the laws of the State of Delaware, United States of America, of Elizabeth, New Jersey, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an apparatus for heating fluids, especially hydrocarbons, in order to convert higher boiling hydrocarbons to more valuable lower boiling products.

More particularly, this invention relates to an apparatus for steam cracking hydrocarbons in a furnace having novel cracking tubes therein, whereby substantial advantages and improved economics are achieved.

The overriding objective in steam cracking hydrocarbons is to convert economically heavy petroleum fractions such as gas oil or naphtha to the more valuable lower molecular weight chemicals which are extensively used as starting materials for the production of even more valuable consumer products. Typically, steam cracking will provide ethylene, propylene, butadiene, and other valuable unsaturated hydrocarbons. The number of important commercial products resulting from steam cracking processes and the derivatives which may be obtained therefrom are obviously too great in number to list in this specification. It is sufficient to note that steam cracking performs the function of providing the building blocks for a multitude of consumer goods, and it is the heart of a petrochemical plant.

In essence, steam cracking as conventionally carried out in today's refinery comprises passing a hydrocarbon feed and steam through a bank or banks of tubes housed within the cracking section of a furnace. In the cracking section of the furnace it is necessary to heat these tubes or coils to temperatures in the order of 2000° F. for the purpose of maintaining fluid temperatures within the tubes between 1300—1500° F. at which temperatures yield patterns and conversion rates are optimum from the standpoint of producing the chemicals demanded by today's industry. Aside from merely subjecting there feedstocks to the above-mentioned high temperatures, it is critically important to maintain high throughput rates for the purpose of minimizing the time during which the hydrocarbons are subjected to these temperatures and it is equally important in many cases to maintain relatively low pressures. Pressures preferably employed are those which are just high enough to insure a rapid throughput rate, it being highly desirable to crack the hydrocarbon feed at a total pressure approaching atmospheric. Accordingly, the pressure drop across the furnace, i.e. from the feed inlet to the product outlet should be minimum. In the cracking section of the furnace straight segments of tubes running parallel to each other and connected by U-bend returns, to provide which is termed a single cracking coil, are disposed either vertically or horizontally depending on the particular cracking furnace designs chosen. In either case, a single pass through the cracking section of the furnace is made by flowing the feed through a single cracking coil which may represent a length several times that of the width or height of the cracking portion of the furnace. There may be plurality of coils representing a bank or banks of coils which are connected at their outlet points whereby the reaction product gases may exit by common outlet means. In a preferred design, there will be employed two banks of cracking coils each disposed in a parallel fashion to the furnace walls bearing the burners which produce the high heat densities required. The term "heat density" refers to the number of BTU's per hour per square foot of coil or tube surface. The rate

at which the feed is passed through the tubes is for practical purposes dependent on the temperature of the reaction product mixture as it exits the furnace. For example, if it is desired to maintain the exit or outlet temperature at 1400° F., means may be provided to control an inlet valve. When the temperature drops below the predetermined 1400° F. level, the inlet valve will automatically restrict the flow of feed to permit longer residence time and higher outlet temperatures. Conversely, when the temperature begins to exceed the predetermined 1400° F., the inlet valve will automatically open to provide a shorter residence time and to cause the temperature to drop toward the predetermined level. Other means are available and may be used if desired.

Past efforts to increase the heat transfer efficiencies of cracking tubes have resulted in the use of external fins or accordian-like transversely corrugated tubes which provided increased tube surface area to tube volume ratio. It is evident that with a given heat density, the use of high tube surface to volume ratios would result in increased heat exchange efficiencies. These techniques, however, embody inherent disadvantages which have caused industry to ignore them in designing commercial units. External fins disintegrate rapidly when subjected to temperatures in the order of 2000° F. This is due to the fact that the fins are isolated from the cooling effect of the fluid within the coils, and the endothermic reaction taking place therein. Even with expensive metals having high thermal resistivity, disintegration of such fins cannot usually be overcome ad frequent shutdowns in order to replace the tubes and/or fins are necessitated.

The use of transverse corrugations and internal fins in order to increase the surface area to volume ratio is subject to other objections. Transverse corrugations and internal fins result in a substantial pressure drop across the cracking coil and as previously noted, a large pressure drop is extremely undesirable. Additionally, the use of internal fins or transverse corrugations provides small areas, e.g. crevices, upon the internal surface within which carbon may deposit, thereby creating decreased heat transfer efficiencies and causing a partial blocking of the cracking oil.

In accordance with this invention, a furnace is provided with tubes having on the internal wall surface a multiplicity of uniform generally longitudinally disposed rounded channels or grooves. In a preferred embodiment the internal wall of the tube will have a multiplicity of continuous generally longitudinally disposed alternating and joining concavities and convexities forming rounded grooves wherein the curvatures of convexities and concavities are approximately equal. It is not essential that the convexities and concavities be joined, however, such a design presents a more practical configuration from the standpoint of manufacture and heat exchange efficiencies. Explaining the tube configuration in more detail, the longitudinal axes of the rounded channels is preferably aligned with the longitudinal axis of the tubes although in some instances it will be more preferable to align them at an angle up to about 45° to the longitudinal axis thereby presenting a spiral-like configuration somewhat resembling the rifling in a gun barrel. The channels referred to are preferably disposed on the internal surface of the tubes although in one embodiment they are disposed on both of the internal and external surfaces.

For a more detailed description of the invention reference is now had to the following description taken with the accompanying drawings wherein:—

Figure 1 represents in section a front elevation of a cracking furnace constructed in accordance with one embodiment of the present invention. Figure 2 represents in section side elevation with parts broken away or omitted for the sake of greater clarity. Figures 3—5 represent in transverse cross-section various embodiments of the cracking coils, and Figure 6 represents one embodiment of the tube shown in longitudinal cross section.

The furnace comprises an enclosure having an outer wall 10 defining essentially two zones. a radiant zone 11 and a convection zone 12. As in the typical furnace, there is provided an inner wall 13 which preferably consists of a refractory material designed to withstand the extremely high temperatures employed in the cracking operation. Burners 14 are provided in the vertical wall of the radiant section and preferably are parallel to the cracking coils 15 within the radiant section. If desired, floor burners 16 may be provided to effect radiation of heat from the floor of the furnace. The number of burners provided will depend on the heat densities required and may vary considerably. In a typical example there will be provided .01 to .20 burners, e.g. .09, per square foot of tube surface, the bulk or all of the burners being disposed on the side walls. The convection section of the furnace relies on the upward movement of combustion or flue gases to provide the necessary heat required to preheat the feed to the desired temperatures. The furnace wall may be designed along conventional lines and may for example include a metal casing (not shown) surrounding the outer wall, as well as conventional supports 17. The flue gas outlet means 18 is provided with a damper 19 for more accurate control of the heat densities required. Describing the coils within the convection and radiant sections of the furnace in a logical order, there is provided near the top of the convection section a single coil 20 which may be employed to preheat water

and to convert it into the steam required for the steam cracking process. Water inlet means 21 and outlet means 22 are provided as shown. In the upper portion of the convection section wherein the water coil 20 is placed, the flue gas temperatures will range from about 400° F. to about 700° F. which provides sufficient heat to increase the water temperature from 130—150° to 220—250° F. Detached from the water coil, feed preheating coil 23, having feed inlet means 24 and preheated feed outlet means 25, is placed within the convection section in the form of a plurality of tube segments 26 connected by return U-bends 27 presenting a serpentine-like appearance. The number of segments and overall length of the preheating coil are, of course, dependent on the specific design of the convection section of the furnace and the flue gas temperatures therein. Steam may be injected into the preheating coil via inlet means 28, the exact positioning of the steam inlet means being variable and dependent on the specific design employed. Steam at a temperature of 425—600° F. is injected into the feed within the preheating coil generally at a point where the feed temperature is somewhat below the steam temperature, i.e. 100—200° F. lower. After the feed, admixed with steam, has passed through the preheat or convection section of the furnace and arrived at the desired temperature, it is then fed into the main cracking coils 29 via inlet means 25. In the present design the cracking coils 29 are vertically disposed in a parallel manner to the side walls of the furnace which bear the primary wall burners. The length of each cracking coil, computed from point A to point B where the individual coil outlet means exit the gases into a common discharge tube 30, will be about 40 to 200, e.g. 100 feet where the coil volume averages from 60 to 230, e.g. 150 cubic inches per linear foot. In the illustration a single coil is shown to contain 5 parallel segments 31 and 4 U-bend returns 32. The common discharge tube 30 may exit the furnace in any convenient location (not shown).

Turning again to the wall burners 14, it will be seen that they are many in number and designed to produce radiant heat as distinguished from heat obtainable by the direct impingement of the flame against the cracking wall. As indicated previous the bulk of the burners is located in the side walls disposed in a parallel manner to the cracking tube banks and in a spaced relationship to provide the cracking coils with a uniform conversion of overlapping radiant heat. It is critical in furnaces of this type to avoid cold spots which result in irregular feed patterns and in the formation of carbon.

In Figure 2, the specific design of the furnace illustrated in Figure 1 becomes even more apparent. It is pointed out that the water preheating coils 20 and the feed preheating coils 23 are not necessarily in parallel banks since the heat provided is by convection rather than radiation. In fact, the preheat coils 23 are preferably staggered within the convection section in a manner which will provide a uniform distance between the coils. This design will result in the greatest heat exchange efficiency within the convection section. The tube segments linearly arranged make up the cracking coils and several coils make up what are referred to as banks 33 and 34 again parallel to the side walls 11 which bear the bulk of the burners 14. The preheat coils may be of the conventional type, cylindrical, i.e. having a circular transverse cross-section.

In accordance with this invention the cracking coils 29 comprises tubes which in transverse cross-section present an undulated configuration. Figures 3—6 in fact represent several embodiments of the generic concept presented in this specification. In Figure 3, the tube 35 has a smooth circular external surface 36 and a generally undulating internal surface wall 37 comprising convexities 38 and concavities 39, which provide rounded longitudinally disposed grooves. The number of such grooves will depend on the desired increase in internal tube surface area over a conventional smooth surfaced cylindrical tube and on other considerations to be described later.

Figure 4 shows in more detail one embodiment of a preferred internally grooved tube configuration, 40 representing the convexities and 41 representing the concavities. The average wall thickness in a typical tube design would be about 0.5 inch for a tube having an outside diameter of about 4.75 inch. Maintaining approximately the same cross-sectional area as a smooth cylindrical tube, it will be noted that the maximum thickness MT as measured from the outside surface of the tube to the apex of a convexity is .625 inch and the minimum thickness mt as measured from the external surface to the apex of a concavity is approximately .375 inch. In Figure 4, these are 16 concavities and a similar number of convexities, forming rounded grooves each having a depth of .250 inch measured from the apex of the adjacent convexities which increases the internal surface area by about 27% over a comparable cylindrical design, i.e. one having the same external diameter and average thickness. In general, it is preferred to utilize a sufficient number of substantially uniform smooth longitudinally disposed convexities and an equal number of concavities so as to provide an increased in surface area of from 5 to 100%. Also, it is preferred to maintain the depth of the grooves within 30 to 200% of the minimum wall thickness, preferably 25 to 100%. Care must be taken to avoid the utilization of too many

undulations which would provide many small ridges and pockets within which carbon deposition would occur. In general, it is preferred to provide the internal surface with a number of grooves equal to 2—8 times the outside diameter calculated in inches.

Figure 5 shows a modification of the present tube design wherein the internal undulations have corresponding external undulations whereby the wall thickness is maintained substantially uniform.

Figure 6 is a longitudinal cross-sectional view of a tube segment of one embodiment of this invention. It shows the grooves aligned at an angle to the longitudinal axis of the tube thereby presenting a spiraling effect.

The longitudinally disposed undulating or grooved design of the present cracking coil eliminates stress raisers such as sharp corners, eliminates coke pockets which would normally be formed by radial fins converging toward the tube center, and would minimize pressure drop since the grooves or valleys are essentially aligned along the longitudinal axis and with the natural flow of the fluids passing therethrough.

The improvement achieved by this invention may be partly due to the fact that the principal barrier to heat transfer in cracking operations is the cake film which forms on the inside surface of the tube. Hence, all of the heat must pass through the coke layer which is usually limited in surface to the internal surface of the tube. By extending the internal surface of the tube, the surface of the coke layer is also extended, thereby permitting a greater and more efficient transfer of heat through this insulating layer. The external surface plays a lesser role in heat transfer efficiency probably because the radiation supplies nearly as much heat as convection to the outside surface. Nevertheless, an extended external surface in conjunction with an extended internal surface as described effects an appreciable improvement in heat transfer efficiency without the use of fins. The use of longitudinally grooved cracking tubes permits increased cracking efficiencies which may be brought about in several different ways. For example, the coil outlet temperature may be increased from 60 to 100° F. for a given conversion and feed rate. A 60° F increase in coil outlet temperature has been found to appreciably increase ethylene, isoprene, and butadiene yields. Alternatively, the feed rates or throughput may be increased from 10— 20% for any given coil outlet temperature and conversion. Tube metal temperatures may be reduced markedly for a given coil outlet temperature, conversion and feed rate. Reduction in tube metal temperatures increases the tube life and minimizes coke deposition, thereby minimizing shutdown time.

For a more comprehensive understanding of this invention, reference is now had to the following operative example which illustrates some of the benefits accruing.

Example

In order to comparatively evaluate the present cracking tube design, a steam cracking furnace similar to the one described above with reference to Figure 1 was employed. This furnace contained two banks of cracking coils with each bank comprising 4 coils or passes. Each coil within the radiant section of the furnace was about 65 feet in overall length and had an internal diameter of 3.75 inches. For this test, one of the standard cylindrical coils was replaced by a coil having the design shown in Figure 4 which was of equal length and which had an internal volume substantially equal to the cylindrical coils. As feed to the steam cracker there was employed a gas oil fraction boiling from about 425 to 650° F. Inlet pressures for all radiant coils were maintained at about approximately 30 psig and 3 moles of steam per mole of hydrocarbon feed were fed into the gas oil fraction feed at a point within the convection section of the furnace as described in this specification. Pressure recorders were installed at the radiant inlet on one of the conventional passes and the grooved tube design pass of this invention. Additionally, flow recorders were installed on the hydrocarbon feed and steam feed to the conventional and novel coils. The metal temperature of the thin and thick portions of the grooved tube, and the conventional tube, were measured with platinum-platinum rhodium thermocouples and recorded continuously at 5-minute intervals. The tube metal temperatures of the cylindrical and undulating coils were also measured with an optical pyrometer. After the steam-cracking operation had apparently reached an equilibrium, the following results were noted.

The heat transfer through the undulating or ripple tube design of the present invention was increased by about 11% over the conventional cylindrical tube. At steady conditions of equal coil and outlet temperatures, steam dilution and coil outlet pressure, the undulating tube design showed a 5—6% increase in gas oil feed over the conventional cylindrical tube with tube metal temperatures averaging 20—25° F. lower than the cylindrical tube. By permitting the tube metal temperature of the ripple design tube to elevate to the same tube metal temperature of the cylindrical tube, an increase of 10—15% in gas oil feed is accomplished. At the lower tube metal temperature the ripple tube showed as high as an 8% increase in feed rate. Since the inside surface wall area in the test radiant coil was 27.2% greater than the internal area of the reference cylindrical tube, the advantages obtained by the use of this novel design as indicated did not go entirely to increased heat transfer as evidenced by increased

feed rate but also to a cooler metal temperature. At the start of the run the ripple tube wall temperature was 1700° F. and the cylindrical tube temperature 1715° F. As the run progressed, this temperature difference of 15° F increased to approximately 35° F after about three months of continuous operation. The final tube wall temperatures at the conclusion of three months run were 1965° F. for the ripple tube and 2000° F. for the cylindrical tube. The increase in tube wall temperatures at the constant feed rate and outlet temperatures employed were attributable to coke buildup. The cooler metal temperatures at which the undulating tube runs effects a much longer tube life.

While the foregoing description and examples refer to a cracking furnace, embodying a particular design, it is to be understood that the ripple tubes are also suitable for other furnace designs such as those employing horizontal cracking coils and, in general, other heat exchange media using radiant heat where high heat exchange efficiencies are desirable.

WHAT WE CLAIM IS:—

1. An apparatus for heating fluids which comprises a furnace having tubes disposed therein, means for introducing cool fluid into the tubes, means for withdrawing hot fluid from the tubes and means for exposing the external surfaces of the tubes to radiant heat, wherein each tube is of uniform cross-section and has an internal surface formed at least in part by a multiplicity of longitudinal rounded channels disposed parallel, or at angle not exceeding 45°, to the longitudinal axis of the tube.

2. An apparatus as claimed in claim 1, in which the channels are formed by alternate and continuous convexities and concavities of the internal surface of the tube.

3. An apparatus as claimed in claim 2, in which the convexities and concavities are of equal curvature.

4. An apparatus as claimed in any preceding claim, in which the external surface of each tube conforms to the internal surface of the tube, whereby the tube is of sub-substantially uniform wall thickness.

5. An apparatus as claimed in any of claims 1 to 3, in which the external surface of each tube is substantially circular in cross-section.

6. An apparatus as claimed in claim 3 and claim 5, in which the convexities and concavities form rounded grooves having a depth equal to form 25 to 100% of the minimum wall thickness of the tube and are provided in sufficient number to increase the internal surface area of the tube by from 5 to 100% of that of a cylindrical tube of the same external diameter and average thickness.

7. An apparatus as claimed in claim 3 or claim 6, in which the convexities and concavities form a number of rounded grooves equal to from 2 to 8 times the external diameter of the tube calculated in inches.

8. An apparatus for heating fluids, and tubes for disposal in such apparatus, substantially as hereinbefore described and illustrated in the accompanying drawings.

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Fig. 1.

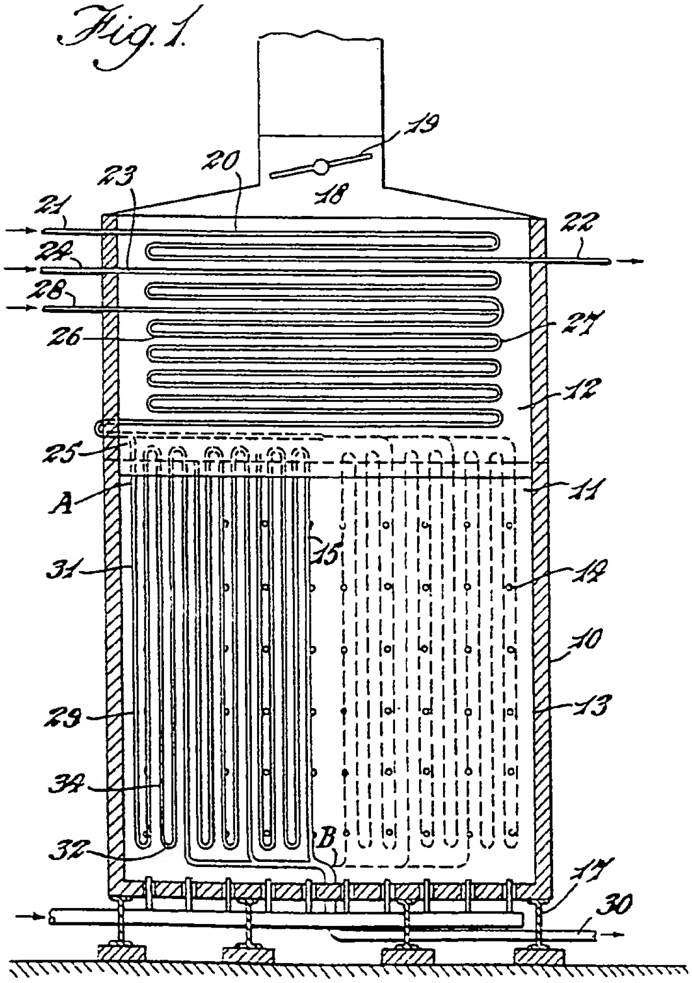
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Fig. 2.

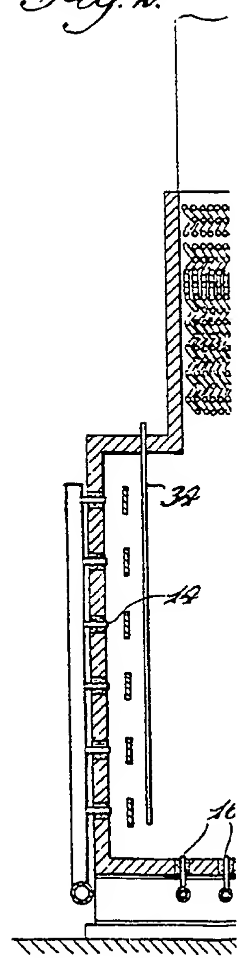
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Fig. 1.

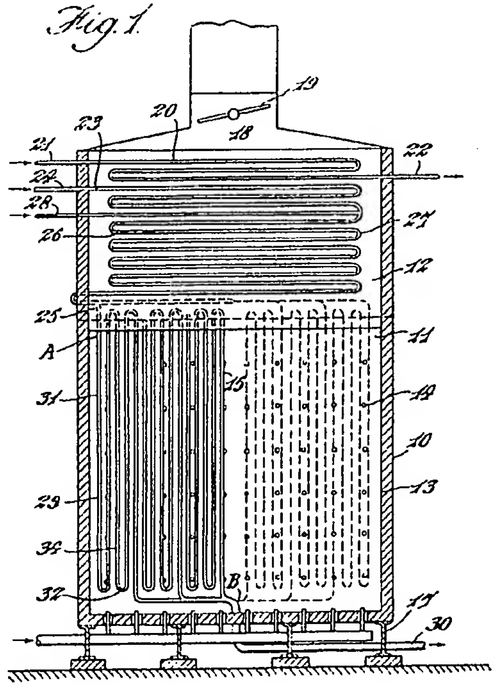

Fig. 2.

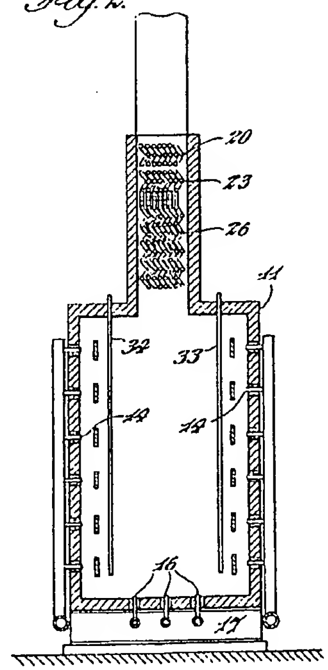

Fig. 4

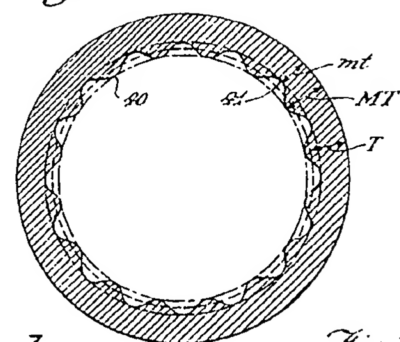

Fig. 3

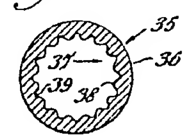

Fig. 5

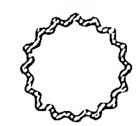

Fig. 6

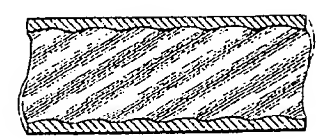

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Fig. 2.

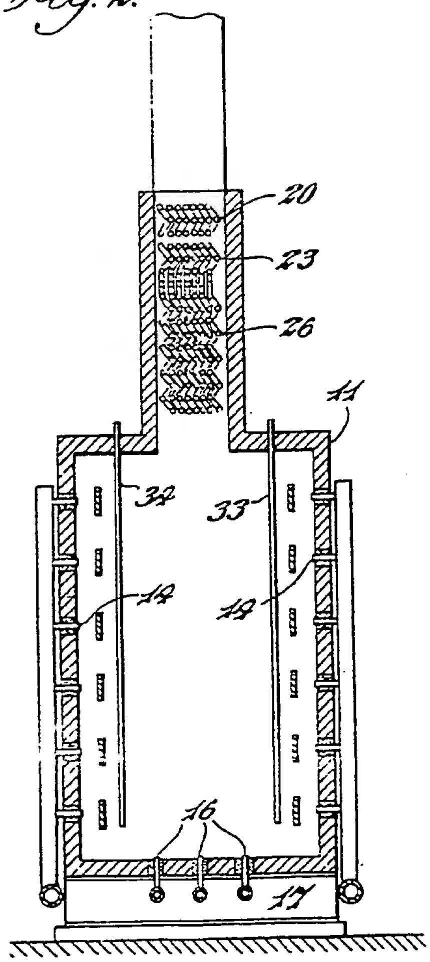

Fig. 4

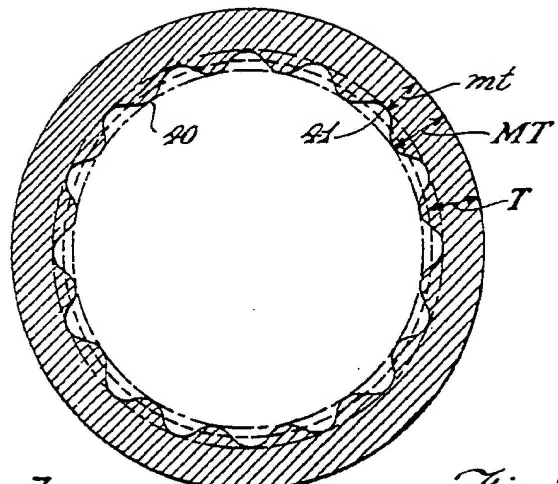

Fig. 3

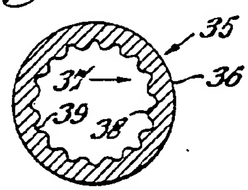

Fig. 5

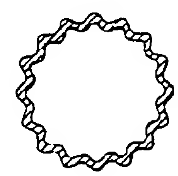

Fig. 6